Bioluminescence Truth Data Measurement and Signature Detection

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LONG-TERM GOALS

The long-term objective is to expand the database of bioluminescence measurements in the world oceans by increasing the number of instruments that are collecting data with standardized, relevant units of measurement.

OBJECTIVES

The primary objectives during this funding period can be summarized into three main tasks:

1.   Continue development of a large scale wireless bioluminescence sensor array designed to measure bioluminescence variability over the short space and time scales that dominate coastal zone bioluminescence.

2.   Continue development of an autonomous drifting profiler designed to aid in mapping and tracking bioluminescent thin-layers and localized aggregations.

3.   Begin development of mobile intelligent distributed sensor platforms designed to hunt for a "best path" solution of low bioluminescence potential over a large spatial area.

APPROACH

Three major challenges face the collection of data needed to develop predictive models of bioluminescence in the coastal zone. These are: 1.) monitoring the short space and time scales of coastal events requires a dense distribution of sensors that are potentially costly, 2.) regions of greatest strategic interest, such as the mouths of major estuaries or rivers are navigable waterways that present bureaucratic challenges for cabled sensor systems and 3.) a wide array of environmental variables must be measured in real-time in conjunction with bioluminescence in order to conduct statistically significant correlation analyses. To meet these challenges a major development effort was put into the creation of a distributed array of low-cost, wireless sensor suites, which are intended to give a long-term and spatially-broad view of coastal bioluminescence activity and related forcing

	Report Documentation Page		*Form Approved* *OMB No. 0704-0188*

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1. REPORT DATE **30 SEP 2007**	2. REPORT TYPE **Annual**	3. DATES COVERED **00-00-2007 to 00-00-2007**

4. TITLE AND SUBTITLE **Bioluminescence Truth Data Measurement And Signature Detection**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Ocean Research & Conservation Association,1420 Seaway Drive,Fort Pierce,FL,34949**	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES **code 1 only**

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

factors (Figure 1). Each sensor package measures salinity, flow speed and direction, package depth, tidal parameters, wave characteristics, package orientation, turbidity and bioluminescence and can communicate with up to 255 other systems via a multi-drop RS-485 connection. Each unit is powered from either a single, internal, rechargeable lithium polymer battery or from an external unregulated supply such as a solar panel or wave energy converter. Bioluminescence is measured with a solid-state sensor array, which was developed based on recent findings with the HIDEX GEN3 Bathyphotometer (Davis et al., 2005) and the data handling incorporates recently developed classification and concentration measurement algorithms, which permit identification to taxon (e.g. dinoflagellates or ctenophores) based on flash kinetics.
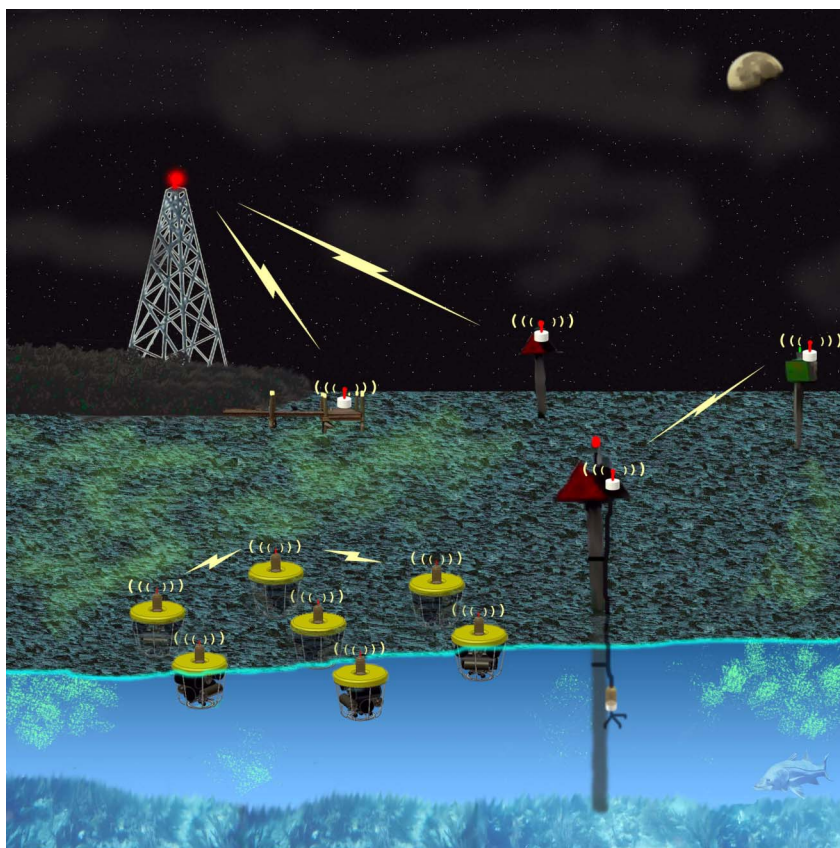

Figure 1: A graphic showing a distributed array of low-cost, wireless sensor suites, which are intended to give a long-term and spatially-broad view of coastal bioluminescence activity and related forcing factors. Kilroy sensors are shown attached to pilings with the senor system below water and the cell phone based communications module attached to the top of the piling. A cell phone tower represents communication of data to shore. Also shown are distributed mobile sensor platforms (Drones) capable of mobile collection of data to be communicated to the fixed wireless sensor network. Bioluminescence is represented as blue-green speckling.

Concurrently, work begun during BTDMSD (Phase 4) on the development of an autonomous drifting bioluminescence profiler (BP Drifter) was completed. This drifting instrument utilizes a modified Webb Research APEX variable-buoyancy profiler, outfitted with GPS, Iridium satellite modem, USBL with acoustic modem, and a UBAT bathyphotmeter, developed by UC Santa Barbara. The purpose and function of the system is to identify and track local thin-layer aggregations of bioluminescence by

conducting semi-autonomous vertical search profiles. Once a thin-layer has been found, the unit can maintain its depth and drift with the aggregation, while being tracked from a surface ship. Complementary high-resolution profiles and sample collections within the thin layer can then be conducted with the HIDEX G3 Bathyphotometer. Upon completion of its mission, the unit surfaces and transmits its data and position via satellite modem.

Finally, a collaborative sub-contract was issued to Dr. Jerry Hamann, Dr. William Spears and Dr. Diana Spears of the University of Wyoming to develop algorithms for bioluminescence plume mapping, tracing and tracking based on previous work in chemical plume tracing using multiple agents (Spears et al., 2004; Zarzhitsky, 2005). This work will transition directly into use on the mobile distributed sensor platforms currently under development at HBOI, and will allow unmanned bioluminescence mapping and "best-path" determination in an uninstrumented or under-instrumented field of interest.

WORK COMPLETED

Wireless network development:

Field tests of Version 2.0 of the environmental monitoring system, operating in tethered mode were conducted in the Indian River Lagoon, Florida. Also completed were successful bench tests of the bioluminescence bathyphotometer's PIN photodiodes, transimpedance amps, integrators, RS-485 communications, pump control, power system and Venturi pump section. Work was also completed on the development of auxiliary power sources, including testing of solar power cells and a preliminary design for a wave energy converter. Additionally, an historical wind record analysis was conducted for the Indian River Lagoon to determine available wave power.

Drifting Profiler:

New CPU and controller modules for the drifting profiler were designed, built, and tested. This new hardware will allow increased functionality, reliability, and data processing capabilities. Additionally, the same controller will be used in the distributed mobile sensor platforms (DRONEs), discussed below. The new CPU and controller (Figure 2) were integrated into the BP Drifter system, along with a high-density Lithium-Ion power unit. The UBAT bathyphotometer and USBL/Acoustic Modem subsystems were also incorporated. Field testing of the complete system, along with simultaneous data collection along-side HIDEX Gen III is scheduled for November 2007.

Figure 2: Completed CPU (left) and controller (right) boards for the Drifting Profiler. These boards will also be used as agent controllers for the DRONE mobile distributed sensor platforms, and are designed to communicate with the fixed wireless sensor network.

Mobile Distributed Sensor Platforms:

To complement the development of the fixed sensor platforms, the creation of a series of floating intelligent, distributed, mobile sensor platforms (called DRONEs) was proposed. These platforms will carry many of the same sensors as the fixed packages, and are capable of communication and data exchange with the fixed stations. To help enable this development, a subcontract was issued to collaborators at the University of Wyoming. UW's Distributed Robotics Laboratory has expertise in the application of cooperative, multi-agent intelligence to problems such as chemical plume tracing in fluid media. These problems closely resemble bioluminescence "best-path" navigation and mapping tasks, and thus show strong promise for application on the DRONE mobile sensor platforms to bioluminescence mapping and tracking. Over the past several months, a 2-dimensional software simulation was built using the StarLogo language, which applies Physicomimetics (or Artificial Physics, AP) methods to the multi-agent "best-path" problem. Using this framework, simulation experiments are now underway to refine these algorithms for use on real hardware in the lab and field during 2008. The primary mission tasks that are currently being addressed in the simulation are:

1. Efficient overall mapping of bioluminescence surface activity in a given area.

2. Identification and tracking of local and global bioluminescence gradients, minima and maxima over a 12-hour period.

3. Real-time determination of the "best-path" solution to reach a goal position while following a bioluminescence minimum or maximum.

In addition to finding novel ways to achieve these tasks, the simulation is currently being enhanced to include other forcing factors, such as wind, tidal currents, and salinity/temperature gradients. The simulated mission area is typically 1 sq. km.

RESULTS

Wireless Network

In the past year significant progress was made in developing data management and presentation software designed to provide an intuitive geospatial representation of biological and physical measurements made from multiple sensors in the wireless sensor array. A data base was developed which separates scientific, maintenance/operations and manufacturing data in which systems are uniquely identified based on position on named sensor strings, thereby allowing systems to drift spatially with no affect on web presentation of data and facilitating regional deployments.

Data is presented spatially using transparent Adobe Flash layers overlaid on Google Maps, which requires no software installation on the user's computer. Icons, representing each Kilroy installation are located based on GPS coordinates telemetered by the cell phone module. Icons point in direction of most recently measured flow and are color-coded based on most recently measured temperature. Moving the mouse over an icon retrieves from the database the most recent measurements for the corresponding sensor package. Gauges beside the map display user-selected variables and change value as the mouse is moved from one icon to the next (Figure 3).
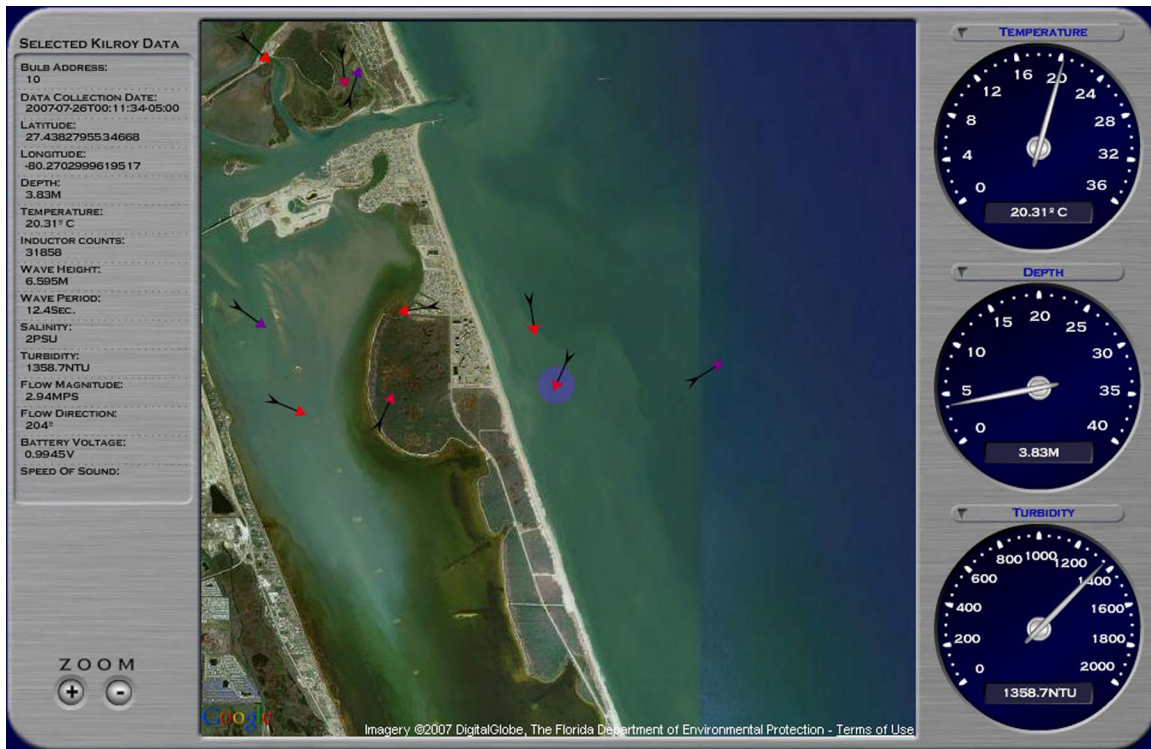
Figure 3: Wireless network data screen showing Google Map satellite view of the Fort Pierce, Inlet, Florida. Icons representing each Kilroy installation are displayed as arrows overlaid on the satellite image that point in the direction of most recently measured flow and are color-coded based on most recently measured temperature. Clicking on an icon displays data on the left-hand side of the screen, shown as data collection date, latitude, longitude, depth, temperature, inductor counts, wave height, wave period, salinity, turbidity, flow magnitude, flow direction, battery voltage and speed of sound. Three gauges on the right-hand side of the screen display user-selected variables which change value as the mouse is moved from one icon to the next. Variables shown are temperature, depth and turbidity.

DRONE Simulations

Testing of the DRONE simulation engine has yielded excellent results thus far. The Artificial Physics (AP) algorithms show good formation cohesion, good path following and high mission success-rate (reaching the goal position is considered success).
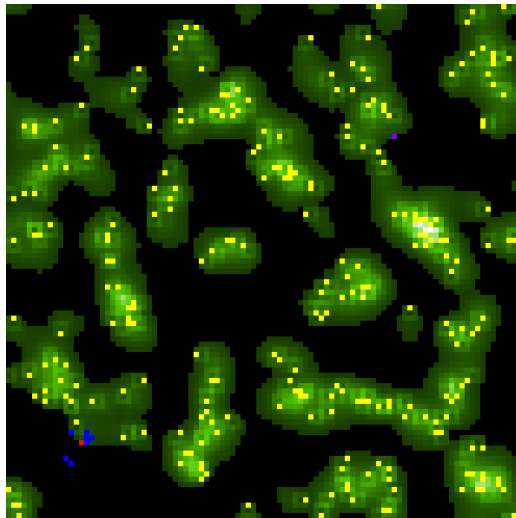
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Figure 4: Seven simulated DRONE vehicles are released into a "bioluminescent minefield". Blue dots at bottom left represent the agents, the red dot is the centroid of the swarm. Green clusters represent bioluminescent aggregations, and the purple dot at upper right represents the goal location.
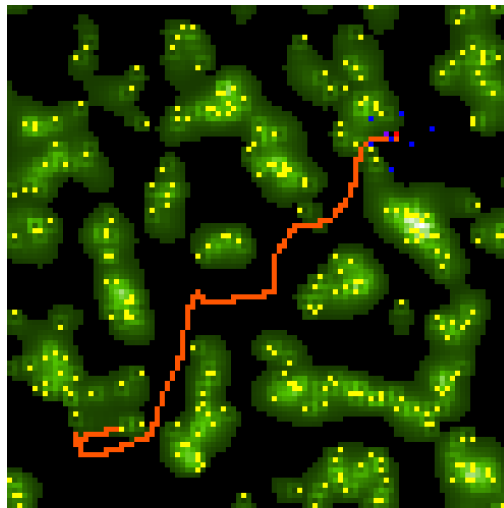

Figure 5: DRONE swarm proceeds to goal location while following a bioluminescent minimum. The red line represents the swarm's track from start to goal. Use of multiple agents helps to decrease the chances of getting stuck in a local minimum (cul de sac).

IMPACT/APPLICATIONS

As naval operations move into coastal waters, the possible impact of sporadic bioluminescent blooms on clandestine operations is of increasing concern. The stealth advantages of the Naval Special Warfare community can be severely undermined by bioluminescence, which may reveal an operation to an adversary with no greater detection capability than the unaided eye of a spotter overlooking a point of ingress or egress. Such points present a difficult challenge for Naval planners, because they

represent regions where watershed runoff can profoundly impact growth conditions of bioluminescent plankton on very short space and time scales. Because of these short time scales, the need for predictive models based on environmental forcing factors has become increasingly critical. The Kilroy sensor webs, the BP drifter and the mobile DRONE sensor platforms are designed to provide Naval planners with critical data needed to predict night-time visibility in the same way that weather stations provide meterologists with the data needed to predict weather.

RELATED PROJECTS

A closely related project entitled, "Monitoring bloom dynamics of a common coastal bioluminescent ctenophore," is being funded under Office of Naval Research Grant Number: N00014-07-1-0532 to test the feasibility of using the Kilroy bathyphotometer and the Kilroy wireless sensor network to monitor bloom dynamics of the common bioluminescent comb jelly, *Mnemiopsis leidyi.*

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